PROCEEDINGS

53. IWK

Internationales Wissenschaftliches Kolloquium
International Scientific Colloquium

Faculty of
Mechanical Engineering

PROSPECTS IN MECHANICAL ENGINEERING

8 - 12 September 2008

www.tu-ilmenau.de

TECHNISCHE UNIVERSITÄT
ILMENAU

Home / Index:
http://www.db-thueringen.de/servlets/DocumentServlet?id=17534

Published by
Impressum

Publisher Herausgeber	Der Rektor der Technischen Universität Ilmenau Univ.-Prof. Dr. rer. nat. habil. Dr. h. c. Prof. h. c. Peter Scharff
Editor Redaktion	Referat Marketing und Studentische Angelegenheiten Andrea Schneider
	Fakultät für Maschinenbau Univ.-Prof. Dr.-Ing. habil. Peter Kurz, Univ.-Prof. Dr.-Ing. habil. Rainer Grünwald, Univ.-Prof. Dr.-Ing. habil. Prof. h. c. Dr. h. c. mult. Gerd Jäger, Dr.-Ing Beate Schlütter, Dipl.-Ing. Silke Stauche
Editorial Deadline Redaktionsschluss	17. August 2008
Publishing House Verlag	Verlag ISLE, Betriebsstätte des ISLE e.V. Werner-von-Siemens-Str. 16, 98693 Ilmenau

CD-ROM-Version:

Implementation Realisierung	Technische Universität Ilmenau Christian Weigel, Helge Drumm
Production Herstellung	CDA Datenträger Albrechts GmbH, 98529 Suhl/Albrechts

ISBN: 978-3-938843-40-6 (CD-ROM-Version)

Online-Version:

Implementation Realisierung	Universitätsbibliothek Ilmenau ilmedia Postfach 10 05 65 98684 Ilmenau

Home / Index:
http://www.db-thueringen.de/servlets/DocumentServlet?id=17534

53rd Internationales Wissenschaftliches Kolloquium
Technische Universität Ilmenau
08 – 12 September 2008

A. Lukács / A. Halmai

Electromagnetic shaker used in cellular Phones

Abstract: Electromechanical part, such as vibration motors, is essential components for mobile phones in order to come up with advance in the communication industry. The traditional vibrating component in mobile phones is a tiny rotating motor having an eccentric weight on top of the shaft. The size reduction, life span, reliability and productivity of mobile phones still remains the most prominent trend in the marketplace and demands a continual effort for the new construction. In this article, design of a linear-electromagnetic actuator is introduced.

Keywords: electromagnetic shaker, linear actuator, vibration motor, cellular phone, mechatronics

1. INTRODUCTION

The mobile phone is an essential gadget in modern society life as a personal communication and multimedia function device. Thus, the mobile phone became one of the most important devices in the communication industry. As the multimedia function requires fast response, long life-time, high performance vibration motors for a silent paging signal, the optimal design using the dynamics characteristics simulation has been a more issue than ever before. Cellular phones use only an ironless, DC micromotor (Fig. 1) based on Lorentz force to cause a vibration function nowadays. Conventional vibration motors employ three-phase windings with a set of mechanical brushes [1], [2].

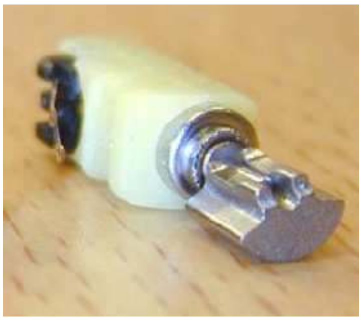

Fig. 1. A vibration motor composed of a DC motor and an eccentric mass called counterweight

It can be seen that the construction of the motors is changing [3,4]. The main endeavor is to put end of the commutation with conventional brushes and commutators [5]. This task can be solved by a brushless DC electric motor but its price does not make competitive. The other way could be the modifying of the present construction. The linear actuator comes here to the front. In this paper is introduced our new, linear-electromagnetic actuator (Fig. 2) and its measurement results. This prototype (Fig. 3) is manufactured by the authors which employs a shaker vibration algorithm.

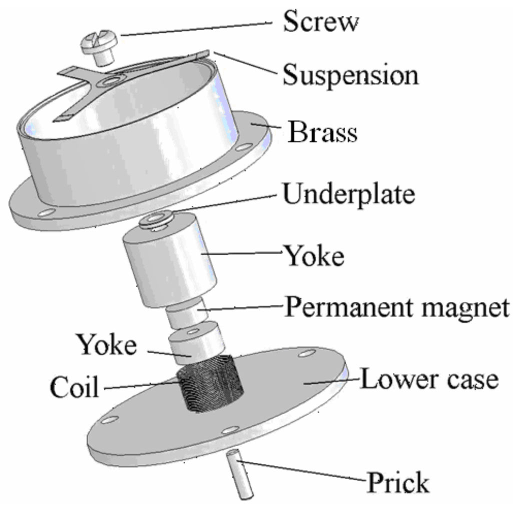

Fig. 2. Schematic drawing of the linear-electromagnetic actuator


Fig. 3. Manufactured linear-electromagnetic actuator

2. LINEAR-ELECTROMAGNETIC ACTUATOR

This part describes our linear-electromagnetic actuator which is used in cellular phones to cause a vibration function. Its usable frequency range is from 140 to about 160*[Hz]* because human skin has the highest sensitivity to vibrating force in this frequency range [6]. The linear electromagnetic actuator derives its name from the method of force generation. The electromotive force – EMF which causes motion is produced electrodynamically by the interaction between a current flow in the coil and the magnetic field which passes through the coil, as illustrated in figure 4.

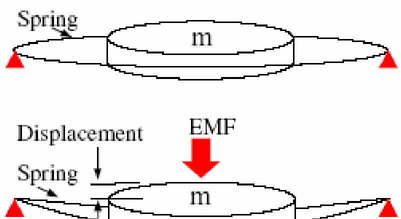

Fig. 4. Schematic diagram of generating the vibrating force of the mass-spring system in the linear electromagnetic actuator without EMF and under EMF

The magnetic exciting force resulting from the interaction between the magnetic field and the total electric currents can be expressed as:

$$F_c = \int I dl \times B \tag{1}$$

The standing coil is located in the annular air-gap of the moving magnet circuit. The yoke is made of soft iron. The mass of the magnetic circuit (yoke, permanent magnet) is called *m[kg]*. The yoke is magnetically energized by an axial permanent magnet with two poles, generating a radially directed field in the air gap, which is perpendicular to the direction of current flow in the armature coil. The generated force in the permanent magnet is in the direction of the axis of permanent magnet, perpendicular to the lower case.

The direction of force is also perpendicular to the coil current direction and to the air-gap field direction. Motion results when current passes through the coil.

The magnetic circuit assembly is supported by metal springs, permitting rectilinear motion, corresponding in direction to the axis of the coil current. Its advantages are a clean waveform, free vibration and rectilinear displacement with little damping (k [Ns/m]→0). The electromagnetic shaker [7] can be described also a one D.o.F. mass-spring system (Fig. 5) which is resonated by electromagnetic force at the fundamental natural frequency of system to generate and transmit the vibration signal to customers.

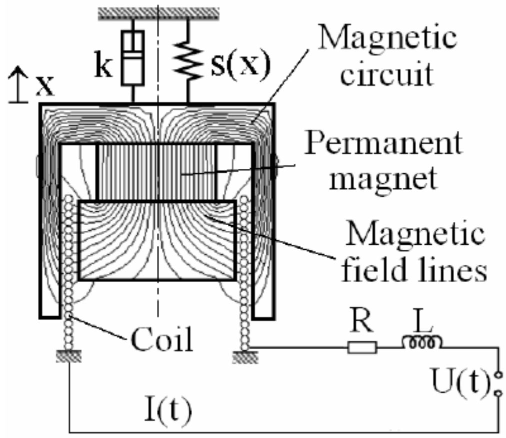

Fig.5. Mechanical and electrical system analogy of the actuator

Coil current - I(t) can also be determined by solving the voltage equation of the equivalent circuit (Fig. 5) :

$$L\dot{I}(t) + RI(t) + BlN\dot{x}(t) = U(t) = U_0 \sin(\omega t) \qquad (2)$$

where *U [V]*, *ω[rad/s]*, *R[Ω]*, *I[A]*, *N[-]* and *L[H]* denote applied voltage, exciting frequency, coil resistant, coil current, number of wires and inductance, respectively. The coil motion generates the back electromotive force, $BlN\dot{x}(t)$, manifesting coupling effects, where *l[m]*, *x(t)[m]* and $\dot{x}(t)$ [m/s] are the coil length, moving magnetic circuit displacement and velocity.

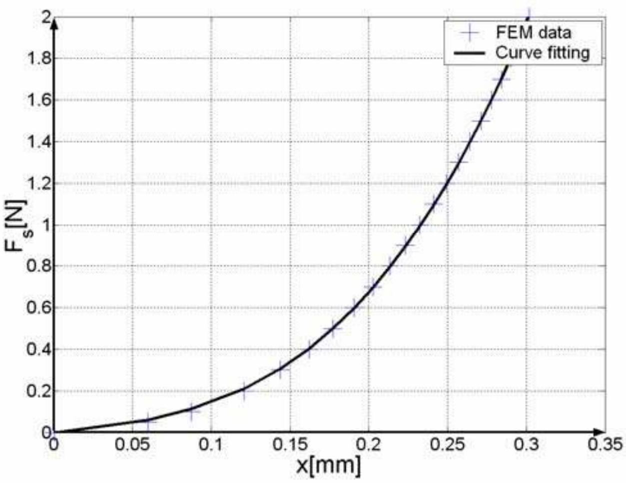

Fig. 6. Restoring force characteristic curves for hardening vibration system

In the simplest case of a spring – mass system is based on the assumption that the elastic spring obeys Hooke's law i.e. the characteristic curve of restoring force versus displacement is a straight line. However, many materials do not exhibit such a linear characteristic like in our case. The spring sometimes exhibits a characteristic such that the restoring force (F_s) increases more rapidly than the displacement. Such characteristic is hardening (Fig. 6).

The prototype has been manufactured using metal springs. The spring force (F_s) – displacement (x) characteristics of our linear electromagnetic actuator was investigated by a finite element analysis. As shown in figure 6 ("+") the restoring force – displacement relationship was a nonlinear function. Our excited system with hardening restoring force may be described approximately by an equation of the form

$$m\ddot{x}(t) + F_s = F_e = BlNI(t) \tag{3}$$

where the $F_s(x) = s(x + \mu x^3)$ equation refers to the hardening characteristic. The *s[N/mm]*, *μ [1/mm2]* are spring stiffness and non-linearity parameter. Curve fitting uses the nonlinear least squares formulation to fit a nonlinear model to FEM data. As noted, a regression equation takes the form in $F_s(x) = s(x + \mu x^3)$. Our goal was to select the values of $s = 0.798\left[N/mm\right]$ and $\mu = 80.6\left[1/mm^2\right]$ that will yield the curve minimizing:

$$\sum_{k=1}^{m}\left(F_i - s(x_i + \mu x^3)\right) = \min. \tag{4}$$

The fundamental natural frequency of the mass-spring system α is calculated as follows:

$$\alpha = \sqrt{\frac{s}{m}}\left(1 + \frac{3}{8}\mu a^2 - \frac{21}{256}\mu^2 a^4 + \ldots\right) \cong \sqrt{\frac{s}{m}} = \sqrt{\frac{798\left[N/m\right]}{0.001\left[kg\right]}} = 893\left[\frac{rad}{s}\right] \cong 142\left[Hz\right] \tag{5}$$

3. STABILITY ANALYSIS

Consider a hardening system whose response curve is shown in Fig. 6. Suppose that the exciting frequency starts at a low value and increases continuously at a slow rate. The amplitude of the vibration (Fig. 7) also increases but only up to a point. In particular, at the point of vertical tangency of the response curve, a slight increase in frequency requires that the system perform in an unusual manner. It "jump" down in amplitude to the lower branch of the response curve. This experiment may be repeated by starting with a large value of exciting frequency, but requiring that the forcing frequency be continuously reduced. A similar situation again is encountered. The system must jump up in amplitude in order to meet the conditions of the experiment. The jump is not instantaneous in time, but requires a few cycles of vibration to establish a steady-state vibration at the new amplitude.

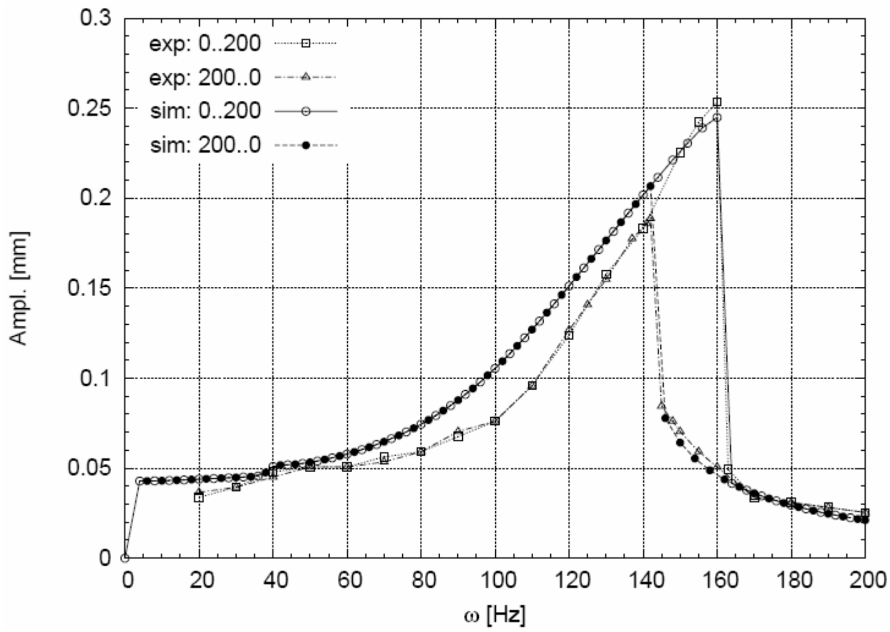

Fig. 7. Response curve for nonlinear system with hardening restoring force characteristic. Response curves obtained from experiment and and simulation

4. CONCLUSIONS

In this work, a new linear-electromagnetic actuator for cellular phones was designed and manufactured using metal springs. The fundamental natural frequency of the linear-electromagnetic actuator was 142[Hz] from equation 5, which satisfy the required range (140-160[Hz]). However, further study needs to calculate the analytical solution of the equation of motion and giving a stability analysis.

References:

[1] A. Halmai, Új konstrukciójú elektromágneses aktuátorok a mechatronikában: A tárcsás forgórészű egyenáramú motorok – Habilitációs értekezés, Budapest, 1997, pp. 11

[2] S. U. Chung and S. M. Hwang, A design of a two-phase permanent magnet vibration motor used for mobile phones, Journal of Applied Physics, Vol. 91, No. 10, May. 2002, pp. 6985-6987

[3] H. J. Lee and S. U. Chung, Development and manufacturing of hexahedral type vibration motor used for mobile phone, Journal of Materials Processing Technology, 130-131, 2002, pp. 685-690

[4] H. J. Lee and S. M. Hwang, Design of an integrated microspeaker and vibration motor used for mobile phones, Journal of Applied Physics, Vol. 93, No. 10, May 2003, pp 8516-8518

[5] S. U. Chung and G. Y. Hwang, Development of brushless and sensorless vibration motor used for mobile phone, IEEE Transactions on Magnetics, Vol. 38, No. 5, September 2002

[6] T. Kaaresoja and J. Linjama, Perception of Short Tactile Pulses Generated by a Vibration Motor in a Mobile Phone, IEEE Proceedings of the First Joint Eurohaptics Conference and Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems, 0-7695-2310-2/2005

[7] T. J. Kim and S. M. Hwang, Analysis of vibration for permanent magnet motors considering mechanical and magnetic coupling effects, IEEE Transactions on Magnetics, Vol. 36, No. 4, July 2000

Authors:

Professor Attila Halmai
PhD student, Attila Lukács
Budapest University of Technology and Economics, Egry József str. 1.
H-1111, Budapest
Phone: +36 1 463 2308
Fax: +36 1 463 3787
E-mail: lukacs@mogi.bme.hu
halmai@mogi.bme.hu